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Far UV and X-ray observations: a hot view of shell galaxies

A. Marino[1], R. Rampazzo[1], G. Trinchieri[2], R. Grützbauch[3], M.S. Clemens[1]

Abstract Shell galaxies are considered the debris of recent accretion/merging episodes. Their high frequency in low density environments suggest that such episodes could drive the secular evolution for at least some fraction of the early-type galaxy population. We present here the preliminary results of ultraviolet and X-ray data for a sample of three shell galaxies, namely NGC 474, NGC 7070A and ESO 2400100. The Far UV morphology and photometry are derived using the observations obtained with the *Galaxy Evolution Explorer* and the XMM-*Newton* Optical Monitor. We aim at investigating the *rejuvenation* processes in the stellar population using the UV information as well as at gaining information about the possible evolution with time of the X-ray emission due interaction/merging processes.

Keywords Ultraviolet: galaxies — X-ray:galaxies — Galaxies: elliptical, lenticular — Galaxies: individual(NGC 474, NGC 7070A, ESO 2400100 — Galaxies: evolution

1 Introduction

In a hierarchical evolutionary scenario, galaxies experience accretion/merging events during their lifetime. While early-type galaxies in nearby clusters appear (homogeneously) old, the field early-type galaxy population seems to contain genuinely, recently *rejuvenated* objects (see e.g. Clemens et al. 2006). Early-type galaxies showing fine structure, like shells, occupy a special position since they are believed to fill the gap between ongoing mergers and normal elliptical galaxies.

Shells are faint, sharp-edged stellar features characterizing ≈ 16.5% of the field early-type galaxy population and avoiding cluster environments (e.g. Malin & Carter 1983; Reduzzi et al. 1996; Colbert et al. 2001). Two major scenarios for their origin have been proposed: *a)* a weak interaction between galaxies (Thomson & Wright 1990; Thomson 1991), *b)* merging/accretion events (Dupraz & Combes 1986; Henquist & Quinn 1987a,b). In the former scenario, weak interaction can form long lasting azimuthally distributed shells through the interference of density waves producing a thick disc population of dynamically cold stars. However, this requires a cold thick disc, not found in ellipticals. In the merging/accretion events between galaxies of different masses (mass ratios typically 1/10 - 1/100, *b)* scenario above) shells are density waves formed from infalling stars from the companion during a minor merger. Major merger can also produce shells (Barnes 1992; Hernquist & Spergel 1992; Hernquist & Mihos 1995). Whatever the mechanism is, interaction/merging events seem to have played a significant role in the formation/evolution of the early-type class in the field and activated a new star formation event (Longhetti et al. 1999, 2000).

Whether there is a link between shell galaxies, the early phases of merging processes, and the class of 'normal' early-type galaxies is still an open question. To test the depth of the link, a multiwavelength approach is of paramount importance. The UV data probe the ongoing/recent star formation processes and study their distribution across the galaxy while the X-ray emission is connected to the past star formation and metal en-

A. Marino, R. Rampazzo, G. Trinchieri, R. Grützbauch, M.S. Clemens

1 INAF - Osservatorio Astronomico di Padova, Vicolo dell'Osservatorio 5, I-35122 Padova, Italy

2 INAF - Osservatorio Astronomico di Brera, Via Brera 28, I-20121 Milano, Italy

3 Institut für Astronomie der Universität Wien, Türkenschatzstrasse 17, 1180 Wien, Austria

richment history of the bulk of the galaxy and may disclose hidden AGN activity.

We present *Galaxy Evolution Explorer* (*GALEX*), XMM-*Newton* Optical Monitor (OM) and XMM-EPIC observations of NGC 474, NGC 7070A, and ESO 2400100, three shell galaxies in the Malin & Carter (1983) catalogue.

2 The sample

Beside the presence of shells, clearly visible in all three, although more spectacular in NGC 474, these galaxies share other properties: they are in low density environments and are interacting systems. However, the details of the interaction are quite different: companions are well separated in NGC 7070A (Ramella et al. 1996) and strongly interacting in NGC 474 as shown by H*I* observations (see e.g. Rampazzo et al. 2006). Two nuclei are embedded and interacting within the ESO 2400100 envelope (Longhetti et al. 1998b). Furthermore, dust is detected in NGC 474 and NGC 7070A, although only for the latter, there is kinematic evidence of an external acquisition.

3 Observations and reduction

Table 1 gives the Journal of the XMM-Newton observations. X-ray data were treated with the standard routines provided by SAS version 7.0 as suggested by XMM-Newton Science Analysis system:Users' Guide available on line[1]. The X-ray observations of NGC 474 have been already discussed in Rampazzo et al. (2006).

[1] `http://xmm.vilspa.esa.es/external/xmm _user_support/ documentation/sas_usg/USG`

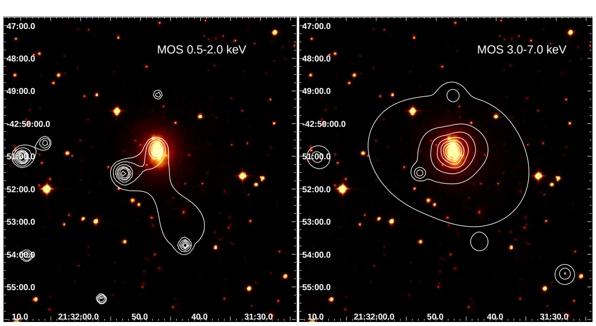

Fig. 1.— Isointensity contours from adaptively smoothed XMM-Newton combined MOS images in two bands on DSS2 plate for NGC 7070A (left panels) and ESO2400100 (right panels).

During X-ray observations, shell galaxies were simultaneously imaged in the ultraviolet and optical bands with the Optical Monitor (Mason et al. 2001)). Observations have been performed using UVW1 and UVM2 bands which cover the ranges 245-320 nm and 205-245 nm, respectively. Galaxies have been observed also in the U (300-390 nm) and B (390-490 nm) bands. The Point Spread Function – FWHM – is $\approx 2.0''$ in UVW1, and $1.8''$ in UVM2 sampled with $0\farcs476 \times 0\farcs476$ pixels.

In order to complete the UV information about our galaxies we searched the *GALEX* archive and retrieved the data for NGC 474. The *GALEX* mission and instruments are fully described in Martin et al. (2005) and Morrissey et al. (2005). The spatial resolution of the images is $\approx 4\farcs5$ and $6\farcs0$ FWHM in FUV (135-175 nm) and NUV (175-275 nm) respectively, sampled with $1\farcs5 \times 1\farcs5$ pixels. We found *GALEX* data only for the NGC 474, that was observed the October 5th, 2003 with an exposure of 1477 and 1647 seconds in NUV and FUV bands respectively.

4 Preliminary results

We aim at obtaining crucial information about the time at which the accretion/merging phenomenon has occured that can be derived from the far UV and optical colours. Such information is important for a proper discussion of the X-ray data. According to the evidence provided by the sample of Brassington et al. (2007), the X-ray luminosity could evolve during the period that characterizes phases of the galaxy-galaxy encounter, the merging and the set-up of the merging towards a relaxed galaxy.

Figure 1 shows the isointensity contours from the adaptively smoothed XMM-*Newton* of NGC 7070A and ESO 2400100 superposed on the DSS plates. It is evident that the emission from these two galaxies has a significantly different morphology. In NGC 7070A the emission is rather compact both in the hard and soft bands. In ESO 2400100 the soft band emission is significantly stronger than the hard one and extends further than in NGC 7070A. Spectral results are in agreement with the spatial picture: the nuclear source of NGC 7070A is the dominant component while in ESO 2400100 the emission is indicative of a low temperature plasma. Rampazzo et al. (2006) showed that NGC 474 is at the bottom of the X-ray emission distribution of E galaxies: its X-ray emission is consistent with the low end of the expected emission from discrete sources.

GALEX data of NGC 474 (Figure 2) show that the NUV emission extends to the galaxy bulge, while the FUV emission shows up only in the central regions

Table 1 Journal of the XMM-*Newton* EPIC and Optical Monitor observations

Galaxy	EPIC PN [sec]	EPIC MOS [sec]	OM UVM2 [sec]	OM UVW1 [sec]	OM U [sec]	OM B [sec]	observing date	observation ident.
NGC 474	4300	11400	5000	5000	5000		2004-01-24	0200780101
NGC 7070A	26250	30840	4400			4000	2004-10-28	0200780301
ESO 2400100	19970	26330	4400	4400	4400		2004-05-11	0200780201

XMM-*Newton* observations of NGC 474 are fully discussed in Rampazzo et al. (2006)

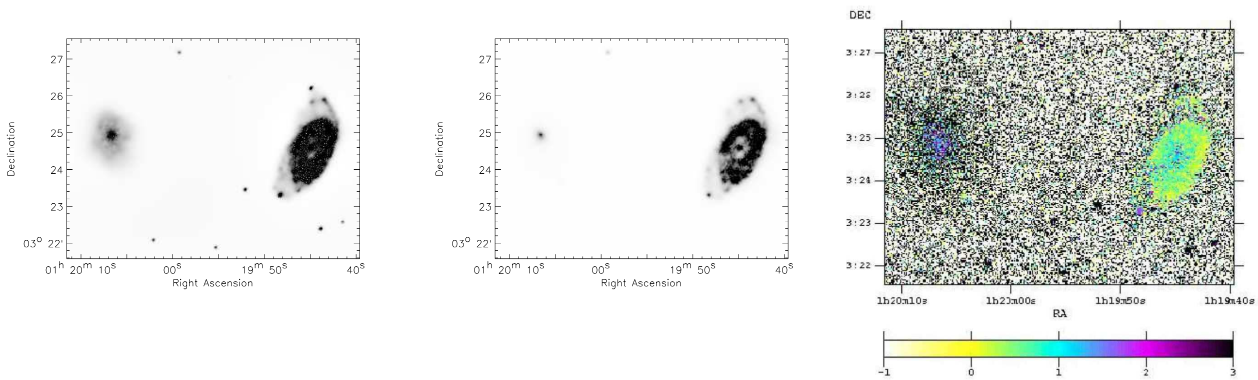

Fig. 2.— The NGC 470/474 system, also known as Arp 227. Full resolution *GALEX* FUV (left panel) and NUV (mid panel) background subtracted images. Pixel by pixel GALEX (FUV-NUV) 2D color map of the NGC 470/474 system (right panel). The (FUV-NUV) color of both the early-type type galaxy, NGC 474, and of the spiral, NGC 470, are typical of their class. Most likely, the NUV and the FUV fluxes have different origins in 'normal' early-type galaxies. The NUV flux is partially due to the MS turn-off stars of the evolved population and partially to more evolved and, exotic stars. In contrast, a strong FUV emission is likely due to the presence of one (or more) hot, plausibly high metallicity, stellar component giving origin to the well known phenomenon of the UV-upturn (e.g. hot-HB and/or post-AGB and AGB-manqué stars). In shell galaxies, the presence of young stars could also contribute in different proportion, to both NUV and FUV fluxes.

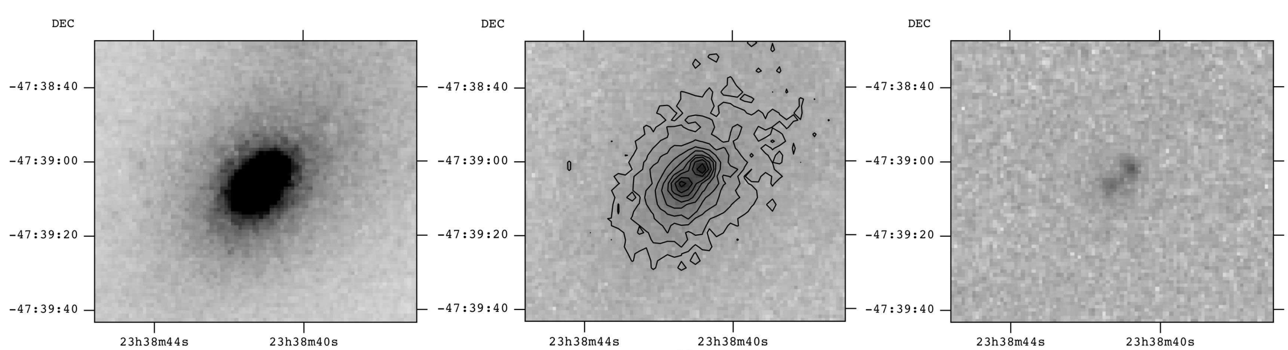

Fig. 3.— U (left panel), UVW1 (mid panel) and UVM2 (right panel) images of ESO 2400100. The two nuclei (we named ESO 2400100*a* the southern, ES0 2400100*b* the northern) embedded in the galaxy body are clearly visible in the UVW1 and UVM2 images.

of the galaxy. In the NGC 474 image obtained in the UVW1 and UVM2 filters outer shells are visible as in the optical image (Rampazzo et al. 2006). Both ESO 2400100 (Figure 3) and NGC 7070A have extension similar to that of the optical image in the OM-UVW1 and in the *GALEX* NUV filter. This implies that the UV emission comes from the same kind of stellar population. The FUV emission, more concentrated toward the nucleus is most likely dominated by the emission of different types of hot stars (see also Rampazzo et al. 2007).

In Figure 3 (mid and left panels) the UVW1 and UVM2 images show the two nuclei embedded in ESO 2400100. The northern nucleus is significantly bluer than the southern one. Longhetti et al. (2000) noticed that the two nuclei have a significantly different Hβ line-strength indices (2.79 in the northern nucleus vs. 1.54 in the southern one) suggesting a different stellar population composition.

The accretion of faint galaxies seems one of the drivers of the secular evolution of galaxies in loose, poor groups. Since shells are widely believed to be generated by an accretion event, shell galaxies potentially trace the typical secular evolution of early-type galaxies in such environments. Furthermore, there is a growing evidence of multiple accretion events in the same galaxy. The complex shell system of NGC 474 is believed to be generated by two distinct accretion events (Sikkema et al. 2007). In this framework the double nucleus in ESO 2400100 is an interesting and puzzling case at the same time. Is the second nucleus the cause of the observed system of shells or another evidence of a new, on-going, accretion event?

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